Exploring the subseasonal weather-climate connection

Edward Berry, National Weather Service
Klaus Weickmann, Climate Diagnostics Center

1. Introduction

Daily monitoring has produced synoptic evidence for fast interactions between the circulation induced by tropical convective flare-ups within the MJO envelope and synoptic-scale waves or wavetrains passing by in the mid-latitudes and/or subtropics. These interactions contribute to the rapid initiation of the composite MJO signal and/or major transitions in weather patterns. The resulting structures can persist as long-lived anomalies in the circulation and the transitions are often accompanied by extreme weather events. To assist with providing an early indication of such situations, a Synoptic-Dynamic Model (SDM) of subseasonal variability has been developed and is applied to evaluating numerical forecasts and to classify and project the current atmospheric state.

2. The Subseasonal Synoptic-Dynamic Model (SDM)

The SDM has four stages based on the MJO time-scale but it incorporates phenomena other than the MJO. Three time scales are included: 1) a “fast” process related to synoptic waves, wave energy dispersion and the mountain torque; 2) an intermediate process related to teleconnection patterns and the global frictional torque; and 3) a quasi-oscillation (~30-70 days) related to the MJO. Studies of tropical-extratropical interaction have documented relationships between mid-latitude circulation modes and the MJO (Weickmann et al., 1985), and these types of linkages, along with their interactions with the 2 other faster time scales, are a feature of the SDM.

Figure 1 presents an illustration of the three time scales that comprise the SDM. On the left side are day 0 regressions of 200hpa vector wind anomalies and sea level pressure onto 1) the global mountain torque representing the fast component, 2) the frictional torque representing the intermediate component, and 3) the first EOF of 20-100 day filtered OLR representing the MJO. On the right side of Fig.1 these three indices are shown for 16 November-March segments from 1979-95. The different time scales are self-evident. The important feature to note in the spatial pattern is their different scale. High amplitude short-wavelength features are associated with the transient mountain torque; Rossby wave like structures across the Pacific-North American region are associated with the friction torque; and zonal wave number 0-2 patterns in subtropical circulation anomalies are linked with the MJO. All three patterns evolve in time and the evolutions are used to help construct the SDM

Before describing the synoptics of the SDM, a brief summary of some model dynamics is presented. The budget of global and zonal atmospheric angular momentum (AAM) provides the dynamical framework. Although budget residuals are large, the time variation of individual terms is still useful for monitoring purposes. The momentum transports are accomplished by anomalous stationary and transient waves. It is the propagation, amplification and decay of these waves that determine weather patterns and regimes important for subseasonal predictions. The dynamical focus at this point is primarily on variations of zonal AAM and the link to regional wave patterns.

Figure 2 (adapted from Peixoto and Oort 1992, and Weickmann 2003 (hereafter W2003)) shows aspects of the time mean and subseasonal dynamics of zonal AAM. Seasonally considerable amounts of momentum are transported across 35N. A small portion of this helps maintain the seasonal AAM balance by linking sources (positive torques) in the subtropics with sinks (negative torques) in the extratropics. The streamlines in Fig. 2 show this link for seasonal and annual means.

The subseasonal zonal AAM budget is dominated by rapidly fluctuating momentum transports tied to baroclinic life cycles and other eddy processes. Such wave-mean flow interactions are an important source of subseasonal variability. In some cases, these stochastic fluctuations can become linked with mountain torques anomalies that span most of the mid-latitudes (e.g., 20-60N). The thick red line in Fig. 2 for DJF illustrates the monopole mountain torque anomaly most common during northern winter. The “+, -, +” represents the zonal wind tendency produced by the transports associated with a positive mountain torque. The tendencies produce zonal mean zonal wind accelerations that eventually reach the surface and help rebalance AAM. The right panel of Fig. 2 illustrates the wavetrains that accompany this process and that are partially responsible for the momentum transports. Not surprisingly, teleconnection patterns are involved. Such extratropical dynamical interactions are a component of the synoptic model.

Figure 3 depicts the four stages of the SDM, roughly 12 days apart. The dark solid (lightly hatched) areas denote regions of negative (positive) outgoing longwave radiation anomalies (OLRA), indicative of enhanced (suppressed) convection. The red (blue) solid lines represent 200 hPa anticyclonic (cyclonic) streamfunction anomalies that show the composite evolution of large scale circulation anomalies during the MJO cycle. They consist primarily of zonal wavenumbers 0-2 and are derived using linear regression on tropical outgoing longwave radiation indices (recall Fig. 1). Twin anticyclones are dominant near or to the west of the convection while twin cyclones occur downstream where equatorial convection is suppressed on average. The MJO life cycle also includes a component shown in “Stage 2” (the heavy brown H and L sequence indicative of 250hpa height anomalies) where a Rossby wavetrain emanates from the western Pacific region. The pattern is transitional compared to the more persistent dipole-dominated patterns shown by the red and blue solid lines, and can lead to extreme cold temperature anomalies across the central USA.

The mid-latitude mountain torque also produces subseasonal variability, especially from Asian and North American topography. The wavetrain depicted at “Stage 1” (the heavy brown L and H sequence), with its location linked to the convection due to the MJO, is associated with a negative mountain torque from these orographic regions. Stochastic links between wave energy passing overhead and the surface pressure anomalies on the mountains' slope can produce a persistent mountain torque. The resulting persistent easterly wind anomalies are concentrated in the subtropics by dynamical processes and eventually reach the surface. A positive frictional torque brings AAM anomalies back to zero. The wavetrain is correlated with the negative phase of the Pacific-North American teleconnection pattern, providing a PNA link to the mountain torque (W2003).

The fastest model component, representing a white noise process, is wave energy dispersion. It is used as a "catch-all" for subseasonal variability not explicitly included in the first two components of the model. The bulk of this variability is associated with synoptic wave energy that disperses eastward from baroclinic developments in the storm track region, or from decaying "blocks" and other quasi-stationary extratropical anomalies. The energy moves east at 20-30 m/s and is dominated by spatial scales of zonal wavenumbers 5-7. Coherent episodes that maintain their identify for large distances are known as baroclinic wave packets. Transient interaction between such dispersion events and tropical convection can lead to transitions in the circulation or the onset of composite MJO circulation anomalies. The persistent anomaly pattern can in turn favor amplified ridges and troughs in certain locations as energy disperses through the pattern. For instance, in panel 1 a trough over the west Pacific anchors the pattern. Energy flowing through the pattern can deepen a trough over the USA High Plains and force an extreme event there. In panel 3, a trough near the date line anchors the wavetrain and wave energy flow can deepen a trough along the U.S. west coast.

To summarize the four stages of the SDM, Stage 1 has the MJO centered across the Indian Ocean near 110E. This is a situation when global AAM is at a negative minimum, and the phases of wavetrains due to the mountains and wave energy dispersions are such as to favor, in a probabilistic sense, a high impact weather event across the Rockies and Plains (winter storm and/or severe local storms, for example). This stage can be thought of as “La Nina” like, with Pacific Ocean anticyclonic wave breaking (Shapiro et al. 2000). Stage 2 is when the convection with the MJO comes to about 150E (about 12 days after Stage 1), and allows a west Pacific wavetrain that can lead to extreme cold across the central part of the country. Stage 3 is when the MJO convection reaches the date line (positive maximum AAM), and leads to circulation state that favors Pacific Ocean cyclonic wave breaking, and possible high impact weather along the USA west coast. Stage 4 is the situation when the MJO convection is weakening east of the date line, with some enhancement of thunderstorm activity across northern South America and over or just east of Africa. In this stage, there may be numerous moist subtropical jets linked with a subtropical wavetrain (Branstator 2002), including one into the southwest USA.

3. Conclusions

It is well known that pattern transitions can lead to high impact weather, and are often not predicted well by the numerical models (e.g., days 3-11), particularly if tropical convective forcing is involved. In addition, the end states that result from these transitions can persist up to roughly 4 weeks (and perhaps longer), and even impact the outcome of a seasonal forecast.
A Synoptic-Dynamic Model of subseasonal variability (SDM) for the northern hemisphere cold season is being used to provide early indications of behaviors such as sudden extratropical circulation transitions. The SDM consists of 3 different time-scales: 1) a “fast” process related to wave energy dispersions (1-2 day decay time), 2) an intermediate process related to teleconnections and index cycles (~8 day decay time); and 3) an oscillatory 30-70 day process linked to the Madden-Julian Oscillation (MJO).

In the context of the CDC MJO website (see http://www.cdc.noaa.gov/MJO/index.html), which is a collaborative international effort involving atmospheric scientists from various forecast centers to predict the MJO and its impacts, in addition to GCM and statistical techniques, the SDM is also available as part of a forecast evaluation process. The latter is demonstrated in the "Climate Discussions" section, where "Real-time Weather Climate Discussions and Predictive Insights" are given.

With respect to the week 1-3 predictions in the "Predictive Insights" section, success has been limited, particularly with the initiation and breakdown of the MJO. There have been situations where a retrogression or transition in the mid-latitude circulation was anticipated before numerical models "caught on". But it is still difficult to pinpoint the final positions of the ridge-trough patterns in the PNA sector after a transition. In general, more experience and further development of the SDM may help provide earlier warning of extreme weather events and abrupt circulation changes that at this stage appear unpredictable.

Future work involves gaining forecast experience with the SDM in a "test bed" type environment. Additionally, further quantitative support of the SDM may be possible from examining case studies of "key events", and perhaps modeling efforts where tropical convective forcing is imposed, such as to provide some evidence of the linkages suggested in the model. These kinds of efforts would lend credence and emphasize the need for a synoptic approach to subseasonal predictions. Finally, in addition to being applied to the CPC USA Hazards Assessment, a global version of the SDM for all seasons, making use of situations when there is interhemispheric circulation symmetry, could be used as part of a planned Global Hazards Assessment.

4. References

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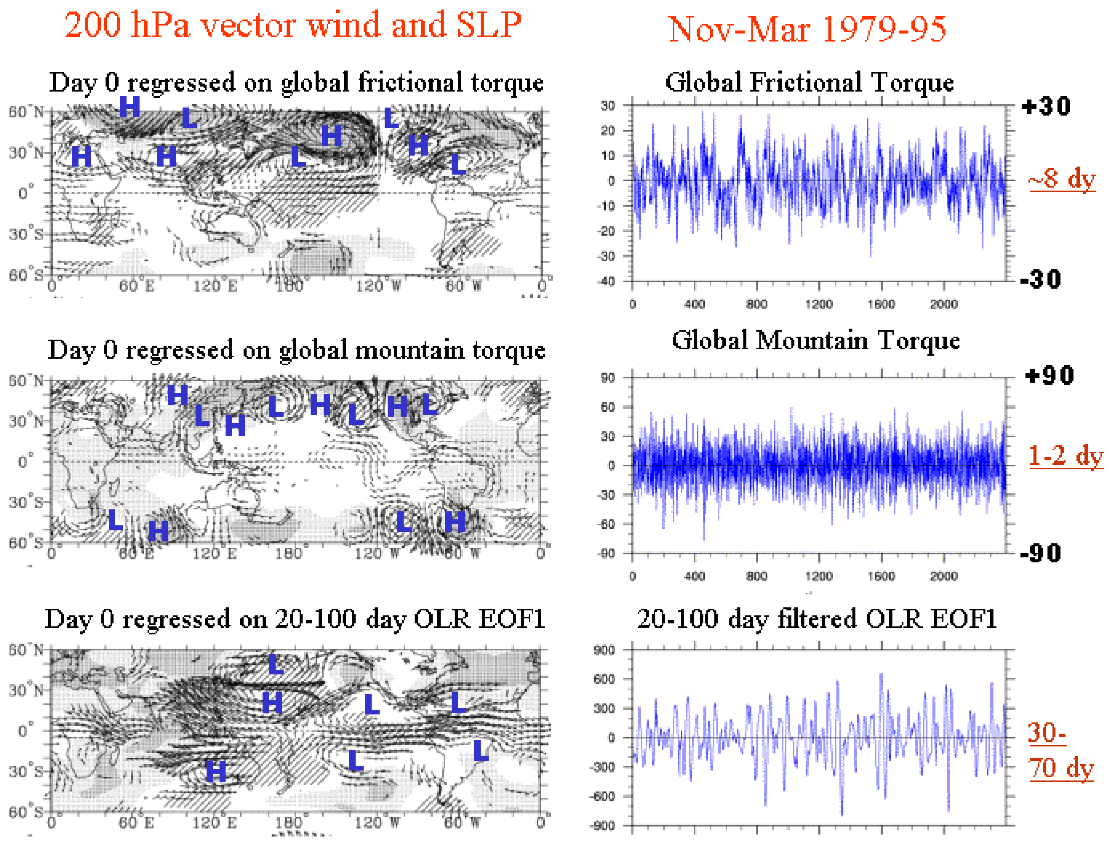
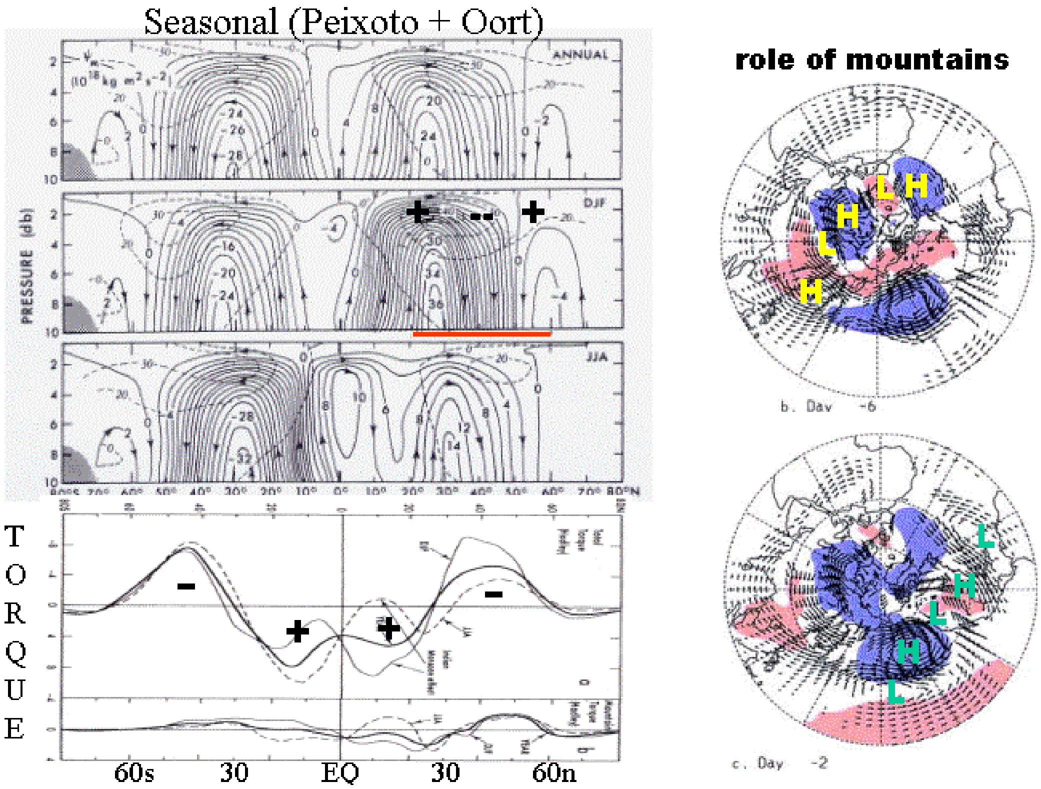


Fig. 1. Left: Day 0 regressions of 200hpa vector wind anomalies and sea level pressure onto the global mountain torque (top), frictional torque (middle) and the first EOF of 20-100 day filtered OLR (bottom). Right: The three indices are shown for 16 November-March segments from 1979-95.

Dynamics of subseasonal AAM variability



Seasonal (Peixoto + Oort)

role of mountains

Fig. 2. Left: Streamlines of the nondivergent component of the zonal-mean transport of relative angular momentum in the atmosphere for annual, DJF, and JJA mean conditions in (top three panels). Bottom panel shows the meridional profiles of the mean surface torque: a) total torque; b) mountain torque only. Units are in Hadleys. Right: Lag regressions of 250-hpa vector wind (arrows) and SLP (shading) anomalies onto the frictional torque at day -6 and day -2. Arrows are plotted after a grid point passes a 98% two-sided significance test, while SLP anomalies greater (less) than 0.5hpa (-0.5hpa) are blue (red).

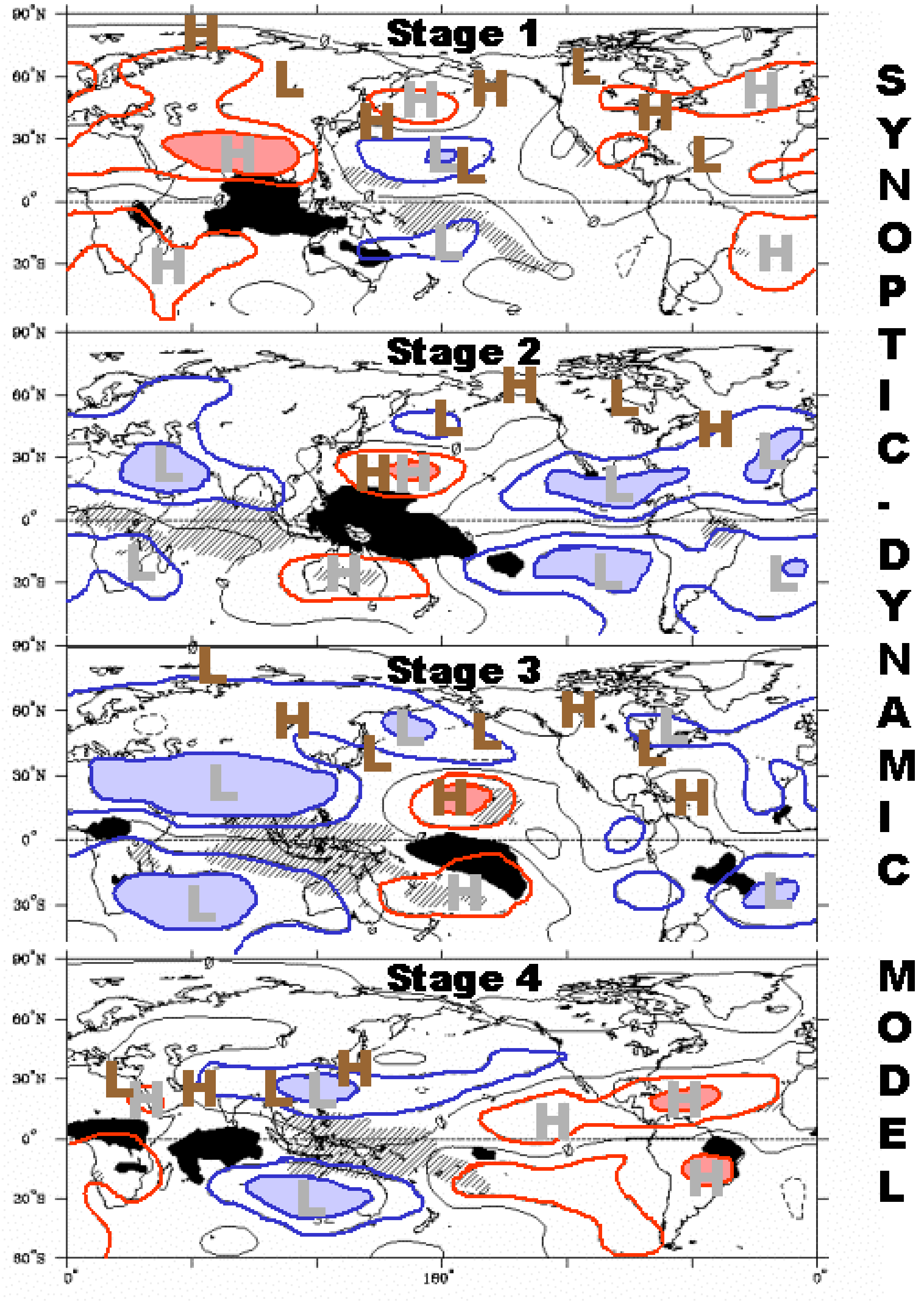


Fig. 3. The four stages of the Synoptic-Dynamic Model. See text for details.